US Army Corps
of Engineers
Afghanistan Engineer District

AED Design Requirements:
Well Pumps & Well Design

Various Locations,
Afghanistan

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AED DESIGN REQUIREMENTS
FOR
WELL PUMPS & WELL DESIGN
VARIOUS LOCATIONS,
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1. General

The purpose of this document is to provide an overview of the information needed by Contractors to design and construct wells for the Afghanistan Engineering District (AED). The document is organized in the following manner. The main body of the document provides information, concepts and guidelines related to site planning, design processes and construction methods. Appendix A provides details and requirements to be followed when applying the concepts presented in the main body. **<u>Appendix A contains the specific information needed to satisfy the requirements of AED projects containing wells and well construction.</u>** Appendix B is a flow chart which provides an overview of the design and construction process. This chart identifies specific activities required by AED and designates when submittals are required during the well design and construction process. Appendix C provides information on acceptable and unacceptable construction techniques and materials used on AED projects. Photographs are provided to help Contractors understand what AED will and will not accept during a well construction project. Appendix D provides information to Contractors which should be used when sizing and selecting pumps for wells on AED projects.

2. Wells

Ground water is subsurface water occupying the zone of saturation. A water bearing geologic formation which is composed of permeable rock, gravel, sand, earth, etc., and yields water in sufficient quantity to be economical is called an aquifer. Unconfined water is found in aquifers above the first impervious layer of soil or rock. This zone is often referred to as the water table. Water infiltrates by downward percolation through the air-filled pore spaces of the overlying soil material. The water table is subjected to atmospheric and climatic conditions, falling during periods of drought or rising in response to precipitation and infiltration. A confined aquifer is defined as an aquifer underlying an impervious bed. Areas of infiltration and recharge are often some distance away from the point of discharge. This water is often referred to as being under artesian conditions. When a well is installed into an artesian aquifer, the water in the well will rise in response to atmospheric pressure in the well. The level to which water rises above the top of the aquifer represents the confining pressure exerted on the aquifer. Materials with interconnecting pore spaces such as unconsolidated formations of loose sand and gravel may yield large quantities of water and, therefore, are the primary target for location of wells. Dense rocks such as granite, slate, etc. form poor aquifers and wells constructed in them do not yield large quantities of water. However, wells placed in fractured rock formations may yield sufficient water for many purposes and water may be of higher quality.

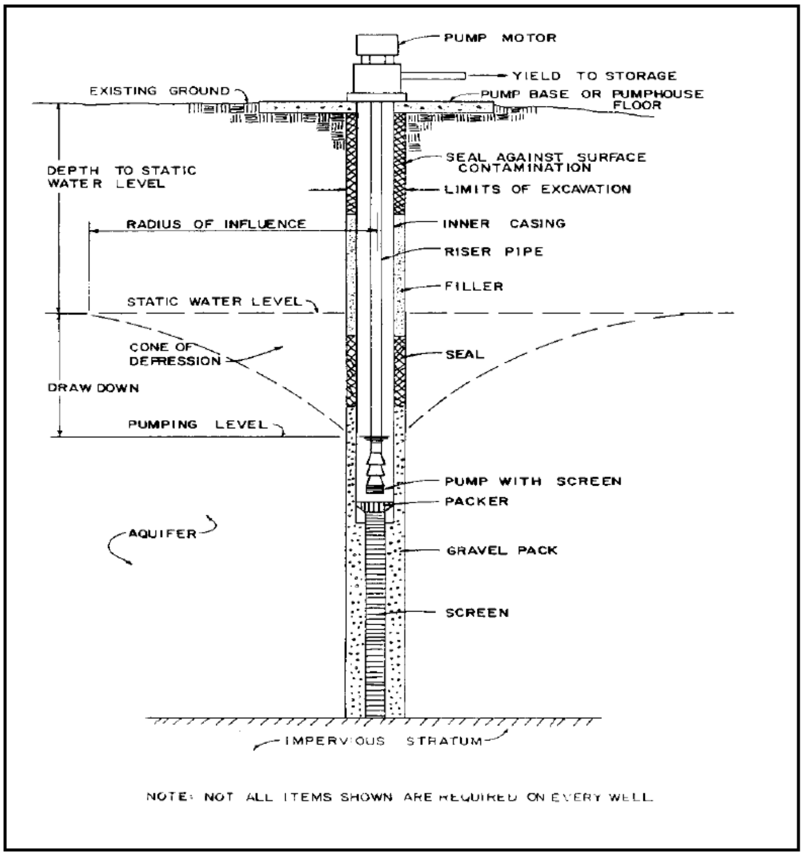
The design features that the engineer or geologist shall consider for drinking water wells constructed on USACE-AED projects includes the following well features:

- Well casing diameter
- Casing materials
- Well and casing depth
- Well screen length and diameter
- Well screen slot openings
- Aquifer and well development and gravel pack material
- Collection and analysis of pump test and water quality data
- Selection of well pump

The design and construction documents must describe the determination of these features in as much detail as needed to provide a permanent record of the well construction. Without this documentation, later attempts to evaluate the potential long term yield of a well, well pump problems, water quality, expected / actual yield, and the potential to increase production will be meaningless.

The well section in Figure 1 illustrates typical features of a well, ground water terms, and approximate location of these features. Most wells in USACE-AED projects will contain electric-powered submersible pumps. However hand-powered pumps may also be specified depending upon the contract technical requirements. Note that the radius of influence caused by pumping is the extent of the cone of depression of the ground water surface around the well. The cone of depression primarily depends on the pumping rate and the aquifer transmissivity. Transmissivity is the rate at which water flows through a vertical strip of aquifer one meter wide and extends through the full saturated thickness under a hydraulic gradient of 1 (100%). Values of transmissivity range from 12 to12,000 m^2/day. If the aquifer transmissivity is 12 m^2/day, a typical 300 mm diameter well, in fine grained material, assumed to have 40 meters of well depth, penetrating the saturated aquifer, with 12 meters of drawdown, producing about 2 liter/second has a radius of influence of approximately 50 meters. This well is adequate for the average daily flow for a 400-man cantonment.

Figure 1. Diagrammatic Section of Gravel-Packed Well



In general, the greater the aquifer transmissivity, the wider the radius of influence of the well. Pumping test data obtained by USACE-AED indicate transmissivity for both fine grained and rock aquifers are at the lower end of the range given above.

3. Types of Wells

Wells are constructed by a variety of methods. There is no single optimum method; the choice depends on the purpose of the well**,** size, depth, formations being drilled through, experience of local well contractors, and cost. The most common methods of installing wells are compared in Table 1. The performance of different drilling methods in different formations is given in Reference 1. The most common type of construction on USACE-AED projects has been drilling using percussion and rotary drilling equipment.

Shallow hand dug wells or caissons using collector systems may be required at PRT project sites or locations where temporary water supplies are needed. These types of wells are not covered in this design guide. They are briefly covered in Reference 2.

Table 1. Types and Methods of Well Installation

Type	Diameter	Maximum Depth (ft)	Lining or Casing	Suitability	Disadvantages	Method of Construction
Dug	3 to 20 feet	40	wood, masonry, concrete or metal	Water near surface. May be constructed with hand tools.	Large number of manhours required for construction. Hazard to diggers.	Excavation from within well.
Driven	2 to 4 inches	50	pipe	Simple using hand tools.	Formations must be soft and boulder free.	Hammering a pipe into the ground.
Jetted	3 or 4 inches	200	pipe	Small dia. wells on sand.	Only possible in loose sand formations.	High pressure water pumped through drill pipe.
Bored	up to 36 inches	50	pipe	Useful in clay formations.	Difficult on loose sand or cobbles.	Rotating earth auger bracket.
Collector	15 feet	130	Reinforced concrete caisson	Used adjacent to surface recharge source such as river, lake or ocean.	Limited number of Installation Contractors	Caisson is sunk into aquifer. Preformed radial pipes are jacked horizontally through ports near bottom.
Drilled	Up to 60 inches	4000	pipe	Suitable for variety of formations.	Requires experienced Contractor & specialized tools.	a. Hydraulic rotary* b. Cable tool percussion* c. reverse circulation rotary d. hydraulic–percussion e. air rotary

4. Water Quality Evaluation

Both well location and method of construction are of major importance in protecting the quality of water derived from a well. Groundwater may become contaminated as a result of leakage from sources as diverse as improperly sealed wells, septic tanks, garbage dumps, industrial and animal wastes, and setback requirements shall be observed for well site selection. In addition, it is important that the well screen, gravel pack, and well pump be carefully designed as a system to insure that wells constructed in fine grained aquifers do not pump silt and fine sand. Pumping sand and silt will limit usefulness of the water and create problems for both the well and the user.

a) Selection of a Well Site. Prior to selecting the well location, a thorough survey of the area should be undertaken. The following information should be obtained and considered:

- Local hydro geology such as terrain, soil type, depth, and thickness of water bearing zone.
- Location of nearby wells, both drilled and hand dug that may limit the well yield or be impacted by the new well
- Location, construction, and disposal practices of nearby sewage and industrial facilities.
- Locations of sewers, septic tanks, cesspools, animal farms, pastures, and feed lots.
- Chemical and bacteriological quality of ground water, especially the quality of water from nearby wells.
- Histories of water, oil, and gas well exploration and development in area.
- Location and operating practices of nearby industrial and municipal landfills and dumps.

- Direction and rate of travel of ground water if studies have been conducted (see Reference 7 as an example for the Kabul Groundwater Basin).

Recommended minimum distances for well sites from commonly encountered potential sources of pollution are shown in Table 2. It is emphasized that these are minimum distances which can serve as rough guides for locating a well from a potential source of groundwater contamination. The distance may be greater, depending on the geology of the area. In general, very fine sand and silt filter contaminants in ground water better than limestone, fractured rock, coarse sand and gravel. Chemical contaminants may persist indefinitely in untreated groundwater. If at all possible, a well should be located up gradient of any known nearby or potential sources of contamination. It is a good practice to consult local authorities for aid in establishing safe distances consistent with the subsurface geology of the area. Dry wells should be abandoned and plugged in conformance to local regulations.

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Table 2. Minimum Distances from Pollution Sources.

Source	Minimum Horizontal Distance
Building Sewer	15 m (50 ft)
Disposal Field / Septic Tank	30 m (100 ft)
Seepage Pit	30 m (100 ft)
Dry Well , Abandoned Well	15 m (50 ft)
Cesspool / Leaching Pits	45 m (150 ft)

Note: the above minimum horizontal distances apply to wells at all depths. Greater distances are recommended when feasible.

Well site planning should also consider the proximity to existing wells both on the project site and in the local community. Equation 3, shown in Section 5, Well Hydraulics, can be used with aquifer pump test data from existing wells to estimate the radius of influence. Reference 8 provides experience for the radius of influence for shallow dug wells. In some regions, depending upon the aquifer and recharge, only one well producing 1.5 L/s on a daily basis may be sustainable in one square kilometer.

The grouping of wells must be carefully considered because of mutual interference between wells when their cones of depression overlap. Minimum well spacing shall be 75 m (250 ft).

The drawdown at a well or any other location on the water table is a function of the following:

- Number of wells being pumped.
- Distance from point of measurement to pumping wells.
- Volume of discharge at each well.
- Penetration of each well into aquifer.

For simple systems of 2 or 3 wells, the method of super position may be used. The procedure is to calculate the drawdown at the point (well) of consideration and then to add the drawdown for each well in the field. For multiple wells, the discharge must be recalculated for each combination of wells, since multiple wells have the effect of changing the depth of water. For large systems the following conditions should be noted:

- Boundary conditions may change.
- Change in recharge could occur.
- Recharge may change water temperature, an increase in water temperature increases coefficient of permeability.
- Computer analysis may be helpful to recalculate the combinations.

It is seldom practicable to eliminate interference entirely because of pipeline and other costs, but it can be reduced to manageable proportions by careful well field design. When an aquifer is recharged in roughly equal amounts from all directions, the cone of depression is nearly symmetrical about the well and is about the same in all directions. If, however, substantially more recharge is obtained from one direction; e.g., a stream, then the surface elevation of the water table is distorted, being considerable higher in the direction of the stream. The surface of the cone of depression will be depressed in the direction of an impermeable boundary because little or no recharge is obtained from the direction of the impermeable boundary.

Where a source of recharge such as a stream, exists near the proposed well field, the best location for the wells is spaced out along a line as close as practicable to and roughly parallel to the stream. On the other hand, multiple water supply wells should be located parallel to and as far as possible from an impermeable boundary. Where the field is located over a valley, the wells should be located along and as close to the valley's center as possible. In hard rock country, wells are best located along fault zones and lineaments in the landscape where recharge is greatest. These are often visible using aerial photographs. Special care should be exercised to avoid contamination in these terrains since natural filtration is limited.

b) Sampling and Analysis. It is mandatory to review water quality requirements contained in the U.S. Department of Defense drinking water standards (see reference 9). Wells supplying water to US Forces must be sampled and analyzed for all of the chemical constituents named in the drinking water standards. Analytical requirements of reference 9 may be supplemented and expanded by contract section 01015, Technical Requirements, to include the more comprehensive sampling requirements given in TM 5-813-3/AFM 88-10, Vol. 3. Major contaminants of concern, heavy metals and arsenic, are rarely encountered in significant concentrations in natural ground waters. There are, however, high concentrations of boron reported in some wells in the Kabul province. Wells supplying water to Afghanistan installations must to meet the World Health drinking water standards (see reference 10).

5. Well Hydraulics

The following definitions are necessary to an understanding of well hydraulics:

- Static Water Level. The distance from the ground surface to the water level in a well when no water is being pumped.

- Pumping Level. The distance from the ground surface to the water level in a well when water is being pumped. Also called dynamic water level.

- Drawdown. The difference between static water level and pumping water level.

- Cone of Depression. The funnel shape of the water surface or piezometric level which is formed as water is withdrawn from the well.

- Radius of Influence. The distance from the well to the edge of the cone of depression.

- Permeability. The ease of which water moves through the rock or sediment.

- Hydraulic Conductivity. Also called coefficient of permeability. The rate at which water moves through the formation (gallons per day per square foot. It is governed by the size and shape of the pore spaces.

The well discharge equation (Eq 1) below is used to determine that amount of water that can be expected from a well. The formula assumes certain simplifying conditions. However, these assumptions do not severely limit the use of the formulas. The assumptions are as follows: 1) the aquifer is of constant thickness, is not stratified and is of uniform permeability; 2) the piezometric surface is level, laminar flow exists and the cone of depression has reached equilibrium; and 3) the pumping well reaches the bottom of the aquifer and is 100 percent efficient. The following equation is used to calculate the discharge from a water table well.

$Q=(K(H^2-h^2))/(1055 \log (R/r))$ Eq. 3

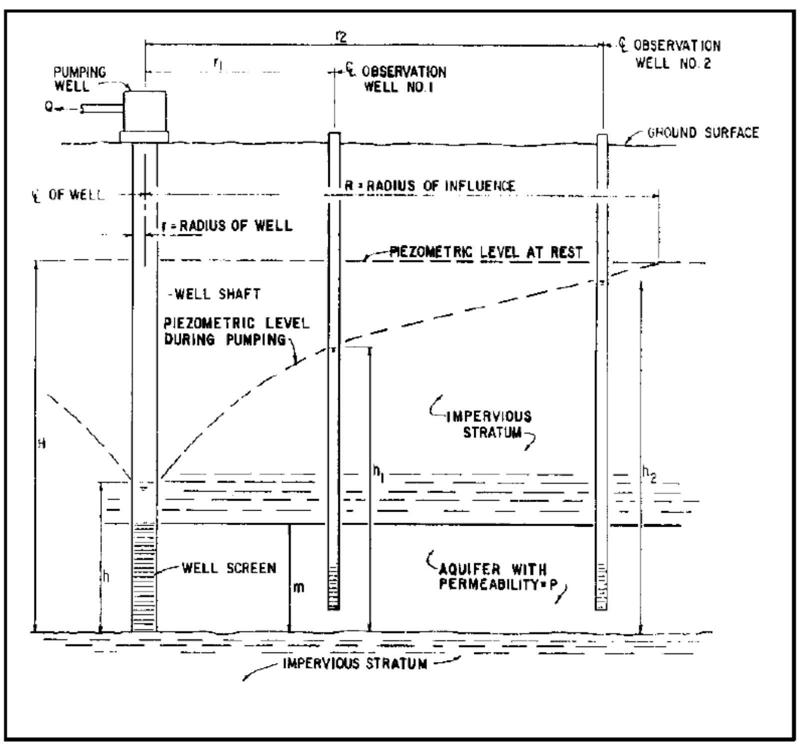
Where:

- Q=pumping rate (m^3/day)
- K=hydraulic conductivity of water bearing unit (m/day)
- H=static head from bottom of aquifer (m)
- h=pumping head from bottom of aquifer (m)
- R=radius of influence (m)
- r=radius of well (m)

Hydraulic conductivity is equal to the aquifer transmissivity dived by the saturated aquifer depth.

Figure 2 shows the relationship of the terms used in Equation 1 for available yield from a water table well. An existing well or monitoring well must be used to estimate the radius of influence of the proposed production well.

Figure 2. Diagram of Water Table Well

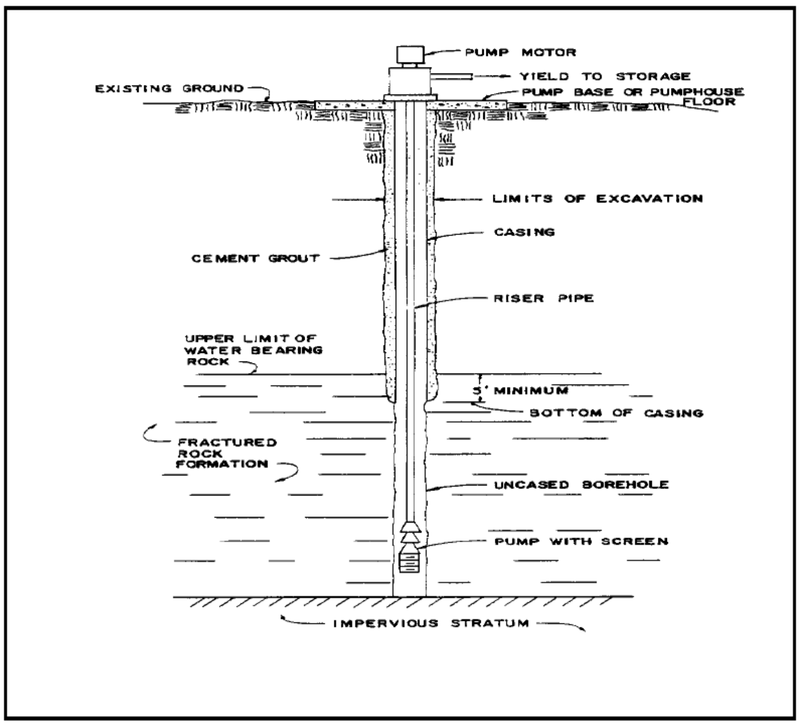


6. Well Design and Construction

The general sequence which should be followed in AED projects is to choose a well site, drill or dig a test hole, test the hydraulic capacity of the well, receive AED concurrence, install permanent well structural elements, develop the well, perform performance tests, install the permanent well pump, and finish the well. See Appendix B for further details regarding this sequence. Test wells and permanent wells should be at least 20 meters below the static water table. The pump, at actual capacity, should have a minimum of 2 meters of submergence at the lowest drawdown depth reached during the pump tests described later in this guide. Well screens shall have a minimum of 2 meters submergence at the lowest drawdown depth occurring during well testing. Permanent wells shall not operate with any portion of the well screen above the lowest drawdown level.

Well design methods and construction techniques are basically the same for water wells constructed in consolidated or unconsolidated formations and only one aquifer is being penetrated. Typically, wells constructed in an unconsolidated formation require a screen to line the lower portion of the borehole. An artificial gravel pack may or may not be required. A diagrammatic section of a gravel packed well is shown in Figure 1. Wells constructed in sandstone, limestone or other creviced rock formations can often utilize an uncased borehole in the aquifer, and do not normally require screens or gravel pack. A well in rock formation is shown in Figure 3. Additional well designs for consolidated and unconsolidated formations are shown in reference 11.

Figure 3. Well in Rock Formation



a) Well casing diameter. The inside diameter for well casings shall selected based on information provided in Table 3. The minimum diameter for any well casing shall be 150mm (6 in). Larger diameters shall be installed based on required well yield and the potential for future expansion. The diameter of a well has a significant effect on the well's construction cost. The diameter shall be uniform from top to bottom. In rare circumstances, construction may be initiated with a certain diameter casing, but drilling conditions may make it desirable to reduce the casing size at some depth. However, the diameter must be large enough to accommodate the pump. In addition, the diameter of the intake section must be sufficient to assure that the upward velocity of the flow in the pump discharge pipe is 1.5 m/sec or less. The well shall be designed to be straight and plumb. Other factors that control diameter are (1) yield of the well, 2) screen intake entrance velocity, and (3) construction method. The pump size, which is related to yield, usually dominates. Approximate well diameters for various yields are shown in Table 3. Well diameter affects well yield but not to a major degree. Doubling the diameter of the well diameter will produce only about 10 to15 percent more water. Table 4 gives the theoretical changes in yield that result from changing from one well diameter to a new well diameter. For artesian wells, the yield increase resulting from diameter doubling is generally less than 10 percent. Consideration should be given to future expansion and installation of a larger pump. This may be likely in cases where the capacity of the aquifer material (such as coarse grained gravels and conglomerate material) is greater than well yield required for the current project

Table 3. Well Diameter vs. Anticipated Yield
In SI and U.S. Customary Units

Anticipated Well Yeild	Nominal Size of Pump Bowls	Optimum Size of Well Casing	Smallest Size Well Casing
(lpm)	(mm)	(mm)	(mm)
<380	100	150 ID	125 ID
285-660	125	200 ID	150 ID
570-1515	150	250 ID	200 ID
1325-2460	200	300 ID	250 ID
2270-3400	250	350 OD	300 ID
3200-4900	300	400 OD	350 OD
4550-6800	350	500 OD	400 OD
6050-11400	400	600 OD	500 OD
(gpm)	(in)	(in)	(in)
<100	4	6 ID	5 ID
75-175	5	8 ID	6 ID
150-400	6	10 ID	8 ID
350-650	8	12 ID	10 ID
600-900	10	14 OD	12 ID
850-1300	12	16 OD	14 OD
1200-1800	14	20 OD	16 OD
1600-3000	16	24 OD	20 OD
3000-6000	20	30 OD	24 OD

Note: If provided, contract section 01015 technical requirements or the guide specifications (Attachment A) shall supersede the minimum diameters suggested in this table

Table 4. Change in Yield for Variation in Well Diameter

Original Well Diameter	New Well Diameter 150 mm (6")	300 mm (12")	450 mm (18")	600 mm (24")	750 mm (30")	900 mm (36")	1200 mm (48")
150 mm (6")	100%	110%	117%	122%	127%	131%	137%
300 mm (12")	90	100	106	111	116	119	125
450 mm (18")	84	93	100	104	108	112	117
600 mm (24")	79	88	95	100	104	107	112
750 mm (30")	76	85	91	96	100	103	108
900 mm (36")	73	82	88	92	96	100	105
1200 mm (48")	69	77	82	87	91	94	100

Note: The above gives the theoretical increase or decrease in yield that result from changing the original well diameter to the new well diameter. For example, if a 300 mm well is enlarged to a 900mm well, the yield will be increased by 19 percent.

The values in the above table are valid only for wells in unconfined aquifers (water table wells) and are based on the following equation:

$$Y_2/Y_1=(\log R/r_1)/(\log R/r_2) \qquad \text{Eq 2}$$

Where:

Y_2=yield of new well
Y_1=yield of original well
R=Radius of cone of depression (mm)
r_2=diameter of new well (mm)
r_1=diameter of original well (mm)

b) Well and casing depth. Depth of a well is usually determined from the logs of test holes or from logs of other nearby wells that utilize the same aquifer. However for contract purposes, a minimum depth is usually specified in either the contract 01015 (Technical Requirements) or in the water well guide specification. A guide specification is provided in this guide as (Appendix A). A well that is screened the full length of the water bearing stratum has a potential for greater discharge than a unit that is not fully screened. Where the water bearing formations are thick, cost may be the deciding factor in how deep the wells are installed. Cost, however, is normally balanced by the savings from a potentially long-term source of water. Well casing should not be founded on bedrock, since the weight of the casing and any other loads transferred to the casing from the construction features may exceed the buckling strength of the casing. The wall friction of the casing after sealing, grouting and well gravel packing should be designed to bear the vertical load on the casing.

c) Casing material. The preferred casing material is steel (ASTM A53 Grade B or ASTM A139 Grade B). Use of PVC must be approved by AED prior to installation. The PVC pipe must be at least Schedule 80 or SDR 17. PVC shall NOT be used for wells deeper than 80m. The casing in a well developed in a sand and gravel formation should extend a minimum of 3 m below the lowest estimated pumping level. In the percussion method of drilling, and where sloughing is a problem, it is customary to drill and jack the casing to the lower extremity of the aquifer, install the appropriate size screen inside the casing, and then pull the casing back, exposing the screen to the water bearing formation. PVC casing shall not be driven or jacked. In consolidated formations, steel casing should be driven 0.50 m into bedrock and cemented in place for its full depth. The wall thickness and pipe strength for the casing material depends on the hydraulic collapse and buckling strengths required for the well. Substitution of other pipe PVC (also called uPVC) for ASTM SCH 80 pipe material shall first be approved by providing a shop submittal (Form 4025) with material specifications sufficient to evaluate the pipe strength for the proposed well application. Reference 3 provides design information used in well casing design.

Table 5 provides the minimum, allowable wall thickness when using Schedule 80 PVC pipe for casing. PVC does not possess the collapse and buckling strength of steel pipe and is limited to relatively shallow wells. PVC casing may be used, only if well depths are less than 80 meters AND with the approval of AED.

Table 5. Minimum PVC SCH 80 Pipe Casing Wall Thicknesses

Casing Diameter		Wall Thickness	
(mm)	(in)	(mm)	(in)
150	6	11	0.43
200	8	13	0.50
250	10	15	0.59

Note: AED does not allow the use of PVC casing in wells deeper than 80 meters.

The minimum wall thickness for steel pipe used for casing is 8 mm. For various diameters, the following Table 6 provides minimum pipe wall thicknesses:

Table 6. Minimum steel pipe casing wall thicknesses by well diameter

Nominal Diameter, mm (in)	Wall Thickness, mm (in)
150 (6)	8 (.250)
200 (8)	8 (.250)
250 (10)	8 (.279)
300 (12)	9 (.330)
350 (14)	10 (.375)
400 (16)	10 (.375)
450 (18)	10 (.375)
500 (20)	10 (.375)

d) Well screens. Well screen shall be 304 stainless steel, unless specified otherwise. Well screens are designed based on the type of aquifer material encountered during drilling which is why it is important to obtain accurate depth information correlated to samples of the material at various depths and changes in strata. Well screens may be sized for aquifers in which the natural development of the formation is feasible. The minimum inside diameter of the well screen shall be 150mm. Such wells completed in sand and gravel with open-end casings, not equipped with a screen on the bottom, usually have limited capacity due to the small intake area (open end of casing pipe) and tend to pump large amounts of sand. A properly designed screen allows the permeability of the water bearing materials around the screen to be utilized. For a well completed in a sand-gravel formation, use of a well screen surrounded by the natural formation (when developed) will usually provide much more water than if the installation is left open-ended or provided with a fine gravel pack. The screen functions to restrain sand and gravel from entering the well, which would diminish yield, damage pumping equipment, and deteriorate the quality of the water produced. Wells developed in hard rock areas do not need screens if the wall is sufficiently stable and sand pumping is not a problem. Appendix B shows examples of acceptable and unacceptable well screens.

The well screen aperture opening, called slot size is selected based on sieve analysis data of the aquifer material for a naturally developed well. For a homogeneous aquifer formations where the well is naturally developed (without a gravel pack), the slot size is selected as one that will retain 40 to 50 percent of the aquifer sand. Use 40 percent where the water is not particularly corrosive and a reliable sample is obtained. Use 50 percent where water is very corrosive and/or the sample may be questionable. Most of the water in Afghanistan is highly corrosive, that is it contains a high concentration of total dissolved solids, and unless the well is drilled into rock corrosive water should be assumed. Where a formation to be screened has layers of differing grain sizes and graduations, multiple screen slot sizes may be used. Where fine sand overlies a coarser material, extend the fine slot size at least one meter into the coarser material. This reduces the possibility that slumping of the lower material will allow finer sand to enter the coarse screen. The coarse aperture size should not be greater than twice the fine size. For a filter packed well, the screen should retain 90 to 100 percent of the filter material. Screen aperture size should be determined by a laboratory experienced in this work, based on a sieve analysis of the material to be screened. Consult manufacturer's literature for current data on screens.

Screen length depends on aquifer characteristics, aquifer thickness, and available drawdown. The minimum screen length shall be two to four meters depending upon the screen material and openings. Minimum total length of PVC screens installed in the permanent well shall be four (4) meters. Minimum total length of stainless steel screens shall be two (2) meters. For a homogeneous, confined, artesian aquifer, 70 to 80 percent of the aquifer should be screened and the maximum drawdown should not exceed the distance from the static water level to the top of the aquifer. For a non-homogeneous, artesian aquifer, it is usually best to screen the most permeable strata.

Homogeneous, unconfined (water-table) aquifers shall be equipped with screens covering the lower one-third to one-half of the aquifer. A water-table well is usually operated so that the pumping water level is slightly above the top of the screen. For a screen length of one-third the aquifer depth, the permissible drawdown will be nearly two-thirds of the maximum possible drawdown. This draw-down corresponds to nearly 90 percent of the maximum yield. Screens for non-homogeneous water table aquifers are positioned in the lower portions of the most permeable strata in order to permit maximum available drawdown. The following equation shall be used to determine if a screen length greater than the minimum screen length stated above is required:

$$L=Q/(AV(7.48)) \qquad \text{Eq 3}$$

Where

L=length of screen (ft)

Q=discharge (gpm)

A=effective open area per foot of screen length (ft^2/ft). Approximately ½ of the actual open area which can be obtained from screen manufacturers.

V=velocity (fpm) above which a sand particle is transported; is related to permeability as follows:

Hydraulic conductivity		Velocity sand transport	
m/day	gpd/ft^2	m/min	ft/min
204	5,000	3.05	10
163	4,000	2.74	9
122	3,000	2.44	8
102	2,500	2.13	7
82	2,000	1.83	6
61	1,500	1.52	5
41	1,000	1.22	4
20	500	0.91	3
10	250	0.61	2

The screen diameter shall be selected so that the entrance velocity through the screen openings will not exceed 0.03 m/s (0.1 foot per second). The entrance velocity is calculated by dividing the well yield in cubic feet per second by the total area of the screen openings in square feet. This will ensure the following:

- The hydraulic losses in the screen opening will be negligible.
- The effect of incrustation will be minimal.
- The effect of corrosion will be minimal.

Various procedures may be used for installation of well screens. For cable-tool percussion and rotary drilled wells, the pull-back method may be used. A telescope screen, that is one of such a diameter that it will pass through a standard pipe of the same size, is used. The casing is installed to the full depth of the well, the screen is lowered inside the casing, and then the casing is pulled back to expose the screen to the aquifer.

In the bail down method, the well and casing are completed to the finished grade of the casing; and the screen, fitted with a bail-down shoe is let down through the casing in telescope fashion. The sand is removed from below the screen and the screen settles down into the final position.

For the wash-down method, the screen is set as on the bail-down method. The screen is lowered to the bottom and a high velocity jet of fluid is directed through a self closing bottom fitting on the screen, loosens the sand and allowing the screen to sink to it final position. If filter packing is used, it is placed around the screen after being set by one of the above methods. A seal, called a packer, is provided at the top of the screen. Lead packers are expanded with a swedge block. Neoprene packers are self sealing.

In the hydraulic rotary method of drilling, the screen may be attached directly to the bottom of the casing before lowering the whole assembly into the well.

Well screen shall be 304 stainless steel, unless specified otherwise.

e) Filter Packing. Filter packing (sometimes referred to as gravel packing) is primarily sand and gravel placed around the well screen to stabilize the aquifer and provide a radius of high permeability around the screen. This differs from the naturally developed well in that the zone around the screen is made more permeable by the addition of coarse material. Filter-pack material is more effective when it is composed of clean rounded sand or gravel. Grain size of the filter pack is selected on the basis of information obtained from sieve analyses of the material in the aquifer. The well screen aperture size will be selected so that between 85 and 100 percent of the filter pack is larger than the screen openings. Criteria for sizing the filter pack are as follows:

Perform sieve analyses on all strata within the aquifer. The ASTM standard sieve sizes to be used in performing these analyses are:

Opening size		ASTM seive
mm	in	No
80	3	4
50	2	10
40	1 1/2	20
25	1	40
20	3/4	60
9.4	3/8	3/8
1.16	0.046	16
0.1	0.004	140

The results of the analysis of any particular sample should be recorded as the percent (by weight) of the sample retained on each sieve and the cumulative percent retained on each sieve (i.e., the total of the percentages for that sieve and all larger sieve sizes). Based on these sieve analyses, determine the aquifer stratum which is composed of the finest material.

Using the results of the sieve analysis for the finest aquifer material, plot the cumulative percent of the aquifer material retained versus the size of the mesh for each sieve. Fit a smooth curve to these points. Find the size corresponding to a 70 percent cumulative retention of aquifer material. This size should be multiplied by a factor between 4 and 6, 4 if the formation is fine and uniform and 6 if the formation is coarse and non-uniform. Use 9 if the formation includes silt. The product is the 70 percent retained size (i.e., the sieve size on which a cumulative 70 percent of the sample would be retained) of the material to be used in the packing.

A uniformity coefficient of 2.5 for the filter pack is desirable. The uniformity coefficient is defined as 40 percent of the retained grain size divided by 90 percent retained size. Lower size represents a more uniform material and is more meaningful for values less than 5.

The plot of cumulative percent retention versus grain size for the filter pack should be approximately parallel to same plot for the aquifer material, should pass through the 70 percent retention value and should have 40 and 90 percent retention values such that the uniformity coefficient is less than 2.5. Filter pack material will be specified by determining the sieve sizes that cover the range of the curve and then defining an allowable range for the percent retention on each sieve. Gradations of sand and gravel packs for typical formation material are provided in the guide specification. However, the contractor shall verify these gradations are suitable for the specific well as not all aquifers are the same.

The thickness of the filter pack will range from a minimum of 50 mm (2 in) to approximately 200 mm (8 in). A filter envelope thicker than about 200 mm (8 in) will not greatly improve yield and can adversely affect removal of fines, at the aquifer-filter pack interface, during well development. Filter pack should extend full length of the screen but not above the top of the aquifer. A tremie pipe may be used to evenly distribute the filter material around the screen and also to prevent bridging of the sand grains. It is important that the filter used for packing be clean and that it also be disinfected by immersion in strong chlorine solution (50 mg/L or greater available chlorine concentration, prepared by dissolving fresh chlorinated lime or other chlorine compound in water) just prior to placement. Dirty filter must be thoroughly washed with clean water prior to disinfection and then handled in a manner that will maintain it in as clean a state as possible.

f) Grouting and Sealing. The well should be constructed to prevent water that is polluted or of otherwise unsuitable quality from entering the well. Grout should extend from the surface to the top of the bentonite seal overlying filter pack of the well. Grouting and sealing of wells are necessary to protect the water supply from pollution, to seal out water of unsatisfactory chemical quality, to protect the casing from exterior corrosion and to stabilize soil, sand or rock formations which tend to cave. When a well is constructed there an annular space between the drill hole and the casing is normally produced, which, unless sealed by grouting, provides a potential pollution channel. A bentonite seal with a minimum thickness of three meters shall be placed directly above the filter pack to prevent vertical infiltration of contaminants through filter material into the well. The wellhead must be grouted and sealed at the surface to prevent contaminants from migrating along the casing into the aquifer.

The well casing and the grout seal should extend from the surface to the depth necessary to prevent surface contamination via channels through soil and rock strata. The depth required is dependent on the character of the formations involved and the proximity of sources of pollution, such as sink holes and sewage disposal systems. The grout around the casing should extend from the top of the bentonite seal to the surface of the well. Local regulations may govern the composition and placement of the grout. Materials for sealing and grouting should be durable and readily placed.

Normally, Portland cement grout will meet these requirements. Grout is customarily specified as a neat cement mixture having a water-cement ration of not over 23 L (6 gal) per 43 kg (94-pound) sack of cement. Small amounts of bentonite clay may be used to improve fluidity and reduce shrinkage. Grout can be placed by various methods, but to ensure a satisfactory seal, it is essential that grouting be:

- Done as one continuous operation.
- Completely placed before the initial set occurs.
- Introduced at the bottom of the space to be grouted.

Establishment of good circulation of water through the annular space to be grouted is a highly desirable initial step toward a good grouting job. This assures that the space is open and provides for the removal of foreign material.

Formations containing water of poor quality above the target aquifer may be sealed off by grouting an outer casing in place before installing the deeper well casing. If the undesirable aquifer is the lower one, care should be taken during drilling so as not to penetrate or breach the confining unit separating the two aquifers. Any portion of the confining unit that is breached should be replaced with grout.

g) Accessibility. The well location shall be readily accessible for pump repair, cleaning, disinfection, testing and inspection. The top of the well shall never be below surface grade. At least 600 mm (2 ft) of clearance beyond any building projection shall be provided.

h) Details Relating to Water Quality. In addition to grouting and sealing, features that are related to water quality protection are:

<u>Location.</u> The well or wells should be located on the highest ground practicable, certainly on ground higher than nearby potential sources of surface pollution. The surface near the site should be built up, by fill if necessary, so that surface drainage will be away from the well in all directions. Where flooding is a problem, special design will be necessary to insure protection of wells and pumping equipment from contamination and damage during flood periods and to facilitate operation during a flood.

<u>Concrete Cover.</u> The well casing should be surrounded at the surface by a concrete slab having a minimum thickness of 100 mm (4 in) and extending outward from the casing a minimum of 600 mm (2 ft) in all directions. The slab should be finished a little above ground level and slope slightly to provide drainage away from the casing in all directions.

<u>Casing Height.</u> The well casing should extend at least 500 mm (20 in) above the level of the concrete surface slab in order to provide ample space for a tight surface seal at the top of the casing. The type of seal to be employed depends on the pumping equipment specified.

<u>Well House.</u> While not universally required, it is usually advisable to construct a permanent well house, the floor of which can be an enlarged version of the surface slab. The floor of the well house should slope away from the casing toward a floor drain at the rate of about 1 mm per 50 mm (1/8 inch per foot). Floor drains should discharge through carefully jointed 100 mm (4 in) or larger pipe of durable water-tight material to the ground surface 6 m (20 ft) or more from the well. The end of the drain should be fitted with a coarse screen. Well house floor drains ordinarily should not be connected to storm or sanitary sewers to prevent contamination from backup. The well house should have a large entry door that opens outward and extends to the floor. The door should be equipped with a good quality lock. The well house design should be such that the well pumps motor, and drop-pipe can be removed readily. The well house protects valves and pumping equipment and also provides some freeze protection for the pump discharge piping beyond the check valve. Where freezing is a problem, the well house should be insulated and a heating unit installed.

The well house should be of fireproof construction. The well house also protects other essential items. These include:

- Flow meter
- Depth gage
- Pressure gage
- Screened casing vent
- Sampling tap
- Water treatment equipment (if required)
- Well operating records

Security. The well building shall be protected from unauthorized use by a security fence having a lockable gate.

7. Well Pumps

a) Pump Type. Many types of well pumps are on the market to suit the wide variety of capacity requirements, depth to water and power source. Electric power is used for the majority of pumping installations. Where power failure would be serious, the design should permit at least one pump to be driven by an auxiliary engine, usually gasoline, diesel or propane. The most appropriate type is dictated by many factors for each specific well. Factors that should be considered for installation are:

- Capacity of well
- Capacity of system
- Size of well
- Depth of water
- Type of well
- Power source
- Standby equipment
- Well drawdown
- Total dynamic head

There are several types of well pumps. The most common are line shaft turbine, submersible turbine, or jet pumps. The first two operate on exactly the same principal; the difference being where the motor is located. Line shaft turbine pumps have the motor mounted above the waterline of the well and submersible turbine pumps have the motor mounted below the water line of the well. Jet pumps operate on the principal of suction lift. A vacuum is created sufficient to "pull" water from the well. This type of pump is limited to wells where the water line is generally no more than 8 m (25 ft) below the pump suction. It also has small capacity capability.

USACE-AED projects commonly employ jet pumps or small submersible turbine pumps. However, there may be projects where other types are preferable. For deep wells with high capacity requirements, submersible or line shaft turbine pumps are usually used and are driven by electric motors. A number of pump bowls may be mounted in series, one above the other to provide the necessary discharge pressure. Characteristics of pumps used in wells are listed in Table 7.

Table 7. Characteristics of Pumps Used in Water Supply Systems

Type of Pump	Practical suction lift	Usual well-pumping depths	Usual pressure heads	Advantages	Disadvantages	Remarks
Reciprocating: 1. Shallow well . . . 2. Deep well . . .	22–26 ft. 22–26 ft.	22–26 ft. Up to 600 feet	100–200 ft. Up to 600 feet above cylinder.	1. Positive action. 2. Discharge against variable heads. 3. Pumps water containing sand and silt. 4. Especially adapted to low capacity and high lifts.	1. Pulsating discharge. 2. Subject to vibration and noise. 3. Maintenance cost may be high. 4. May cause destructive pressure if operated against closed valve.	1. Best suited for capacities of 5–25 gpm against moderate to high heads. 2. Adaptable to hand operation. 3. Can be installed in very small diameter wells (2" casing). 4. Pump must be set directly over well (deep well only).
Centrifugal: 1. Shallow well a. straight centrifugal (single stage)	20 ft. maximum	10–20 ft.	100–150 ft.	1. Smooth, even, flow. 2. Pumps water containing sand and silt. 3. Pressure on system is even & free from shock. 4. Low–starting torque. 5. Usually reliable and good service life.	1. Loses prime easily. 2. Efficiency depends on operating under design heads & speed	1. Very efficient pump for capacities above 50 gpm & heads up to about 150 feet.
b. Regenerative vane turbine type (single impeller)	28 ft. maximum	28 ft.	100–200 ft.	1. Same as straight centrifugal except not suitable for pumping water containing sand or silt. 2. They are self–priming.	1. Same as straight centrifugal except maintains priming easily.	1. Reduction in pressure w/increased capacity not as severe as straight centrifugal.
2. Deep well a. Vertical line shaft turbine (multi–stage)	Impellers submerged	50–300 ft.	100–800 ft.	1. Same as shallow well turbine.	1. Efficiency depends on operating under design head & speed. 2. Requires straight well large enough for turbine bowls and housing. 3. Lubrication & alignment of shaft critical. 4. Abrasion from sand.	

Depending upon contract technical requirements, a hand pump may also be included in the well pump building. This hand pump allows water to be extracted from the well during periods when power is not available. Hand pump components should be stainless steel and the head and flow requirements must be selected based on site conditions.

b) Pump Capacity. The design capacity of the pump must equal the system requirements. Well pump capacity shall be capable of supplying one average day flow (ADF) in a 16 hour period unless stated otherwise in the contract documents. However, the capacity of the pump must never exceed the capacity of the well. Pump manufacturers publish charts giving the pump discharge capacity for their particular pumps at various operating pressures. The total dynamic head (TDH) of the system must be calculated accurately from the physical arrangement and is represented by the following:

$$TDH=H_S+H_D+H_F+(V^2/2g) \qquad \text{Eq 1}$$

Where:

H_s=suction lift; vertical distance from the waterline at drawdown under full capacity to the pump centerline, m
H_D=discharge head; vertical distance from the pump centerline to the pressure level of the discharge pipe system, m
H_F=friction head; loss of head on pipe lines and fittings, m
$V^2/2g$=velocity head; head necessary to maintain flow, m

The brake horsepower of the motor used to drive the pump may be calculated from the following equation:

$$P=(HQ)/(102*e) \qquad \text{Eq 2}$$

Where:

P=break power required, kW
H=total dynamic head, m
Q=volume of water discharged, L/s
e=Combined efficiency of pump and motor, from manufacturer's data

Appendix C contains information for designers on selection of water well pumps.

8. Development and Disinfection

After the structure of the well is installed, there remain two very important operations to be performed before the well can be put into service. Well development is the process of removing the finer material from the aquifer around the well screen, thereby cleaning out and opening up passages in the formation so that water can enter the well more freely. Disinfection is the process of cleaning and decontaminating the well of bacteria that may be present due to the drilling action.

a) Well Development. Three beneficial aspects of well development are to correct any damage or clogging of the water bearing formation which occurred as a side effect of drilling, to increase the permeability of the formation in the vicinity of the well and to stabilize the formation around a screened well so that the well will yield sand-free water.

A naturally developed well relies on the development process to generate a highly permeable zone around the well screen or open rock face. This process depends upon pulling out the finer materials from the formation, bringing them into the well, and pumping them out of the well. Development work should continue until the movement of fine material from the aquifer ceases and the formation is stabilized.

Artificial filter packing provides a second method of providing a highly porous material around the screen. This involves placement of a specially graded filter in the annular space between the screen and the wall of the excavation. Development work is required if maximum capacity is to be attained.

Development is necessary because many drilling methods cause increases in the density of the formation around the hole. Methods utilizing drilling fluids tend to form a mud cake. Good development will eliminate this "skin effect" and loosen up the sand around a screen. Removal of fines leaves a zone of high porosity and high permeability around the well. Water can then move through this zone with negligible head loss.

Methods of development in unconsolidated formations include the following:

> Mechanical surging is the vigorous operation of a plunger up and down in the well, like a piston in a cylinder. This causes rapid movement of water which loosen the fines around the well and they can be removed by pumping. This may be unsatisfactory where the aquifer contains clay streaks or balls. The plunger should only be operated when a free flow of water has been established so that the tool runs freely.
>
> Air surging involves injecting air into a well under high pressure. Air is pumped into a well below the water level causing water to flow out. The flow is continued until it is free of sand. The air flow is stopped and pressure in an air tank builds to 700 to 1,000 kilopascals (100 to 150 psi). Then the air is released into the well causing water to surge outward through the screen openings.
>
> Over pumping is simply pumping at a higher rate than design. This seldom brings best results when used alone. It may leave sand grains bridged in the formation and requires high capacity equipment.
>
> Back washing involves reversal of flow. Water is pumped up in the well and then is allowed to flow back into the aquifer. This usually does not supply the vigorous action which can be obtained through mechanical surging.
>
> High velocity jetting utilizes nozzles to direct a stream of high pressure water outward through the screen openings to rearrange the sand and gravel surrounding the screen. The jetting tool is slowly rotated and raised and lowered to get the action to all parts of the screen. This method works better on continuous slot well screens better than perforated types of screens.

Development in rock wells can be accomplished by one of the surging methods listed above or by one of the following methods.

> Explosives can be used to break rock formations. However it may be difficult to tell in advance if the shooting operation will produce the required result.
>
> Acidizing can be used in wells in limestone formations. Fractures and crevices are opened up in the aquifer surrounding the well hole by the action of the acid dissolving the limestone.
>
> Sand fracturing is the action of forcing high pressure water containing sand or plastic beads in to the fractures surround a well. This serves to force the crevices open.

b) Disinfection of Completed Well. The disinfection of the completed well shall conform to Guide Specifications (Attachment A). Bacteriological samples must be collected and examined in accordance with Standard Methods for the Examination of Water and Wastewater.

c) Disinfection of Flowing Artesian Wells. Flowing artesian wells often require no disinfection, but if a bacteriological test, following completion of the well, shows contamination, disinfection is required. This can be accomplished as follows. The flow from the well will be controlled either by a cap or a standpipe. If a cap is required, it should be equipped with a one-inch valve and a drop-pipe extending to a point near the bottom of the well. With the cap valve closed, stock chlorine solution will be injected, under pressure, into the well through the drop-pipe in an amount such that when the chlorine solution is dispersed throughout all the water in the well, the resultant chlorine concentration will be between 50 and 100 mg/L. After injection of the required amount of stock chlorine solution, compressed air will be injected through the drop-pipe, while simultaneously partially opening the cap valve. This will permit the chlorine solution to be mixed with the water in the well. As soon as chlorine is detected in the water discharged through the cap valve, the air injection will be stopped, the cap valve closed and the chlorinated water allowed to remain in the well for 12 hours. The well will then be allowed to flow to waste until tests show the absence of residual chlorine. Finally, samples for bacteriological examination will be collected in accordance with Standard Methods for the Examination of Water and Wastewater. If the well flow can be controlled by means of a standpipe, disinfection can be accomplished as described for a water table well.

9. As-Builts

Upon completion of installing the well and well pump, the Contractor shall submit editable CAD format As-Built drawings. The drawing shall show the final product as it was installed in the field, with the exact dimensions, locations, materials used, logs and any other changes made to the original drawings. Refer to Contract Sections 01335 and 01780A of the specific project for additional details.

10. References

1. Groundwater and Wells, Fletcher Driscoll, Johnson Division, 1986.
2. UFC 3 230 07a Water Supply Sources General Considerations, 2004
3. Handbook of Groundwater Development, Roscoe Moss Company, 1990
4. ASTM F480-06b Standard Specification for Thermoplastic well Casing Pipe and Couplings Made in Standard Dimension Ratios, SCH 40 and SCH 80
5. ASTM D 1785-06 Standard Specification for PVC Plastic Pipe, Schedules 40, 80 and 120
6. ASTM A 53 Pipe, Steel, Black and Hot-dipped, Zinc-coated, Welded and Seamless
7. Inventory of Ground-Water Resources in the Kabul Basin, Afghanistan, U.S. Geological Survey, Scientific Investigations Report, 2005-5090.
8. Guidelines for Sustainable Use of Groundwater in Afghanistan, Norwegian Church Aid, 2002
9. Sanitary Control and Surveillance of Field Water Supplies, TB MED 577, Department of Defense 2005
10. World Health Organization, Guidelines for Drinking Water Quality, 2006
11. AWWA A-100-06 Water Wells
12. Water Wells and Pumps, Michale,A.M.; Khepar, S.D., and Sondhi, S.K., McGraw Hill, 2008

Appendix A

Guide Specification for Drinking Water Wells
USACE-AED Various Locations, Afghanistan

INDEX

1. APPLICABLE PUBLICATIONS: Publications listed below form a part of this specification to the extent referenced. Publications are referred to by the basic designation .

a. Sanitary Control and Surveillance of Field Water Supplies, TB MED 577, Department of Defense 2005

b. World Health Organization, Guidelines for Drinking Water Quality, 2006

1.3 American Society for Testing and Materials (ASTM) Publications.

A-53 Pipe, Steel, Black and Hot-dipped, Zinc-coated, Welded and Seamless

C-150 Portland Cement

1.4 American Water Works Association (AWWA) Publications.

Standard Methods for the Examination of Water and Wastewater

A100-06 Standard for Water Wells

C200 Steel Water Pipe 6 Inches & Larger

C206 Field Welding of Steel Water Pipe

2. LOCATION AND DEPTH OF WELL: The test well to be constructed shall be located as shown on the drawings, or where directed by the Contracting Officer (CO) or his representative (COR). The well shall be to such depth as may be necessary to penetrate a desirable water-bearing stratum. The minimum well depth for each well shall be 20 meters below the static water table. Additional depth to be determined based on the experience of the driller and similar wells in the area may be required by estimating the additional depth that may be required to provide a minimum 2 meters of submergence over the well pump during the dynamic drawdown of water during test pumping. It may be necessary for the well depth to penetrate the full thickness of the aquifer to bedrock to achieve sufficient depth.

3. LOCAL CONDITIONS: Hydrogeological and water-well information for the immediate vicinity should be obtained locally from private and/or government organizations. The driller should drill test hole as hereinafter specified to assure the water availability of the aquifer. The method of drilling and the type of well construction may vary depending on the local geology. Wells completed into unconsolidated aquifers may need to be screened depending upon the type of aquifer material or if completed into consolidated (rock) aquifers, open-hole construction may be approved.

4. PROTECTION OF EXISTING FACILITIES: The existing facilities such as building structures, utilities, walks, trees, etc., except as otherwise specified in these specifications, shall be protected from damage during construction of the wells, and if damaged, shall be repaired by the Contractor at his expense. Water pumped from the well shall be conducted to a place where it will be possible to dispose of the water without damage to property or the creation of a nuisance.

5. PROTECTION OF QUALITY OF WATER: The Driller shall take all necessary precautions during construction to prevent contaminated water, gasoline or other contaminated materials from entering the well either through the opening or by seepage through the ground surface. The Driller shall exercise extreme care in performance of his work in order to prevent the breakdown or caving of the strata overlying that from which the water is to be drawn.

6. TEST WELL DEVELOPMENT: Before permanent well construction, at least one test well of at least 150mm in diameter and minimum 20 meters below the static water table shall be drilled into the water bearing stratum or the top of bedrock. A GPS instrument will be used to determine the geographic coordinates of the well. This information shall meet requirements of the World Geodetic System 1984 (WGS 84 and the correct UTM Zone – 41, 42, or 43) in decimal degrees. The test hole shall be used to determine the location and character of the water bearing strata and to obtain samples of the various formations. Samples of drilling cuttings shall be taken at every change of strata and at depth intervals not to exceed 1.5 meters. A split spoon sample shall be taken at each major change in strata as

indicated by the nature of the cutting samples. A driller's log shall be made based on the cuttings obtained. The final selection of the screen settings, the proper gravel filter pack material, and the depth of grouting will submitted to the COR for approval prior to any additional work. The drill cuttings shall be divided, put into suitable containers and labeled. These samples shall be approximately half a liter each. If the test hole fails to indicate the presence of water bearing strata or is abandoned for any other reason, the test hole shall be grouted from the bottom to the top with cement grout as hereinafter specified and in a manner approved by the COR. At the completion of the test hole, a drillers log shall be prepared containing the following information that shall be included in the Driller Log Submittal:

a) Depth of water strata
b) Depth of different material strata contacts
c) Color, size, and soil description of cuttings
d) Penetration rate (meters per day)
e) Types and amount of drilling fluid gain or loss
f) Type schedule and length of well casing

7. TEST WELL PUMPING. To determine the expected yield from the well and to assure acceptable water quality, a pump test shall be performed in the candidate test well. A temporary casing and screen, if required, shall be used to construct the test well for execution of a 3 phase step-drawdown test and a 24-hour constant volume capacity test per AWWA 100-6 requirements. (The intervals provided in Table 6 later in this specification may be used to record data during the 3 phase step-duration and the constant volume capacity tests.) The 3 phase step-drawdown test shall test the well at 75%, 100% and 150% of the design flow required for the well. The duration of the test shall be adequate to develop the straight line plots defined by AWWA. A temporary pump with the capacity to pump at the rates may be used for this test. The static water level in the well should be measured prior to installing the pump and the water level at the end of the pumping period should be measured. The temporary casing shall be a minimum diameter of 150mm and extend to the top of the water bearing strata being tested in unconsolidated formations. The Contractor shall isolate other water bearing strata present from discharging into the test well. After completion of the test well, all data pertaining to the construction of the well shall be shown on a sketch of the test well with all pertinent depths of construction.

8. APPROVAL OF TEST WELL. **CONSTRUCTION OF THE WELL SHALL STOP.** Before any further construction in the test well, AED shall receive, review and approve the Test Well Approval Submittal and shall authorize construction of the permanent well. The contents of the Test Well Approval Submittal shall include:

(a) Location of well on site plan.
(b) Size of well diameter and depth.
(c) Driller Log Submittal (Section 6, above)
(d) Depth below top of well of static water table.
(e) Casing and screen diameters and lengths installed in the test well
(f) Well Screen and Gravel Pack Submittal (Section 9.5, below)
(g) Proposed permanent casing diameter and material

(h) Proposed permanent screen design with sand analysis results
(i) Proposed permanent grouting and sealing
(j) Proposed permanent gravel/filter pack design and materials and supporting calculations
(k) Proposed placement depths of gravel pack material, if used.
(l) Test well pumping rate, liters per second
(m) Test well drawdown and recovery records (see Table 6)
(n) Water quality results (see Table 4)

Test wells not approved, shall be abandoned in accordance with AWWA A 100-106.

9. WELL CONSTRUCTION:

9.1 GENERAL: **Construction of the permanent well shall not begin before AED review and approval of the Test Well Submittal.** Failure to follow the construction and submittal procedures outlined, may at AED's discretion, result in rejection of the well and, the contractor having to remove the well casing and screen, re-drill the well and reinstall the proper features per the approved design. Well construction shall be based on well design guidelines set forth in the latest edition of the US Army Corps of Engineers Afghanistan Engineer District (AED) Design Requirements, Well Pumps and Well Design guide. Test wells and permanent wells should be at least 20 meters below the static water table. The pump, at actual capacity, should have a minimum of 2 meters of submergence at the lowest drawdown depth reached during the pump tests described later in this guide. Well screens shall have a minimum of 2 meters submergence at the lowest drawdown depth occurring during well testing. Permanent wells shall not operate with any portion of the well screen above the lowest drawdown level. The execution of the work shall be by a competent crew performed under the direct supervision of an experienced well driller acceptable to the COR. The well shall be drilled essentially straight, plumb and circular from top to bottom. The type of well construction, as determined by the test hole, shall be either an artificially gravel packed well, a naturally developed well or a rock wall well. The presence of cavities and voids in the formations being penetrated will make the construction of a screened well difficult due to loss of the filter material into the cavity. Grouting may also be affected by these voids. If cavities and voids are encountered in the test hole, the Contractor shall consider this in the design of the completed well and submit this information with the results of the test hole and test well. The well shall be constructed and developed to produce clear water with a minimum of drawdown. Wells not meeting the criteria for water quality, Section 10 WELL DEVELOPMENT, will not be acceptable. Well and casing dimensions shall generally be within the following ranges shown in Table 1.

TABLE 1 Minimum Required Well and Casing Diameters

anticipated water yield, l/s	well casing/ screen ID, mm	well diameter, mm
<6.3	150	200
6.4 to 11.0	200	250
11.1 to 25.25	250	300

9.2 SURFACE CASING: Surface casing shall be used on all wells. This casing may be left in place or removed at the option of the driller. If the surface casing is to be left in place, the surface casing shall be grouted into place for the full length of the casing. In unconsolidated aquifer material, casing shall be extended to the top of the well screen. In wells developed in rock formations, the hole may be left open with the casing extended three meters into the formation. All well surface casing shall be extended 0.5 meters above grade.

9.3 WELL CASING: The well casing shall be steel unless PVC is specifically authorized for use by AED. The casing diameter shall be selected per information provided in the AED Design Requirements – Well Pumps and Well Design, latest edition. The casing shall be constructed of ASTM A-53 black steel pipe conforming to AWWA C200 or PVC plastic Schedule 80 meeting ASTM 1785 and ASTM F480 specifications. Only standard weight black steel pipe shall be used as casing for wells over 80 meters deep. The minimum steel casing thickness shall be 8 mm. Steel casing may be provided with drive shoes at the option of the driller. Steel pipe couplings shall be per ASTM F480. PVC casing may be used if well depths are less than 80 meters. Driving of PVC casing will not be allowed. PVC pipe couplings shall be per ASTM F480. All casing used in the permanent well shall be new and unused. Cast iron pipe shall not be used for well casing or screens. Sufficient casing centralizers shall be used to keep casings centered in the hole. Each section of casing will be joined with standard couplings; full-threaded joints, proper welding or solvent cement PVC welds so the joints are sound and watertight. Well casing alignment shall not interfere with the proper installation and operation of the pump.

9.4 CEMENTING WELL CASING: The annular space between the well casing and the walls of the hole shall be filled with cement grout or crushed angular gravel as hereinafter specified. The grout shall be proportioned of Portland cement conforming to ASTM Specification C-150, Type I or II and the minimum quantity of water (not over 23 liters per 42.3 kg of cement) required to give a mixture of such consistency that it can be forced through the grout pipes. The method for placing the grout will be by the forcing of the grout from the bottom of the space to be grouted towards the surface. The minimum depth of grouting shall be three meters unless approved in writing by the COR. The grout shall also seal off any other water bearing strata above the zone that is producing the water to the well. The grouting shall be done continuously and in a manner that will insure the entire filling of the annular space in one operation without damaging the well casing. No drilling operations or other work in the wells will be permitted within 24 hours after the grouting operation to allow the grout to properly set. Up to 5% bentonite may be added to the mixture to reduce shrinkage of the grout. The addition of bentonite will require additional water at the ratio of 2.5 liters of water for each percent of bentonite added. The bentonite slurry shall contain at least 20 percent solids by weight by having a density of 4.3 kg/L. Aggregate requirements for sealing the solid wall casing and edge of the borehole area shown below:

Sieve Size (mm)	Percent total weight passing (%)
12.5	100
4.75	75 +/- 13
1.18	25 +/- 15
.075	8 +/- 4

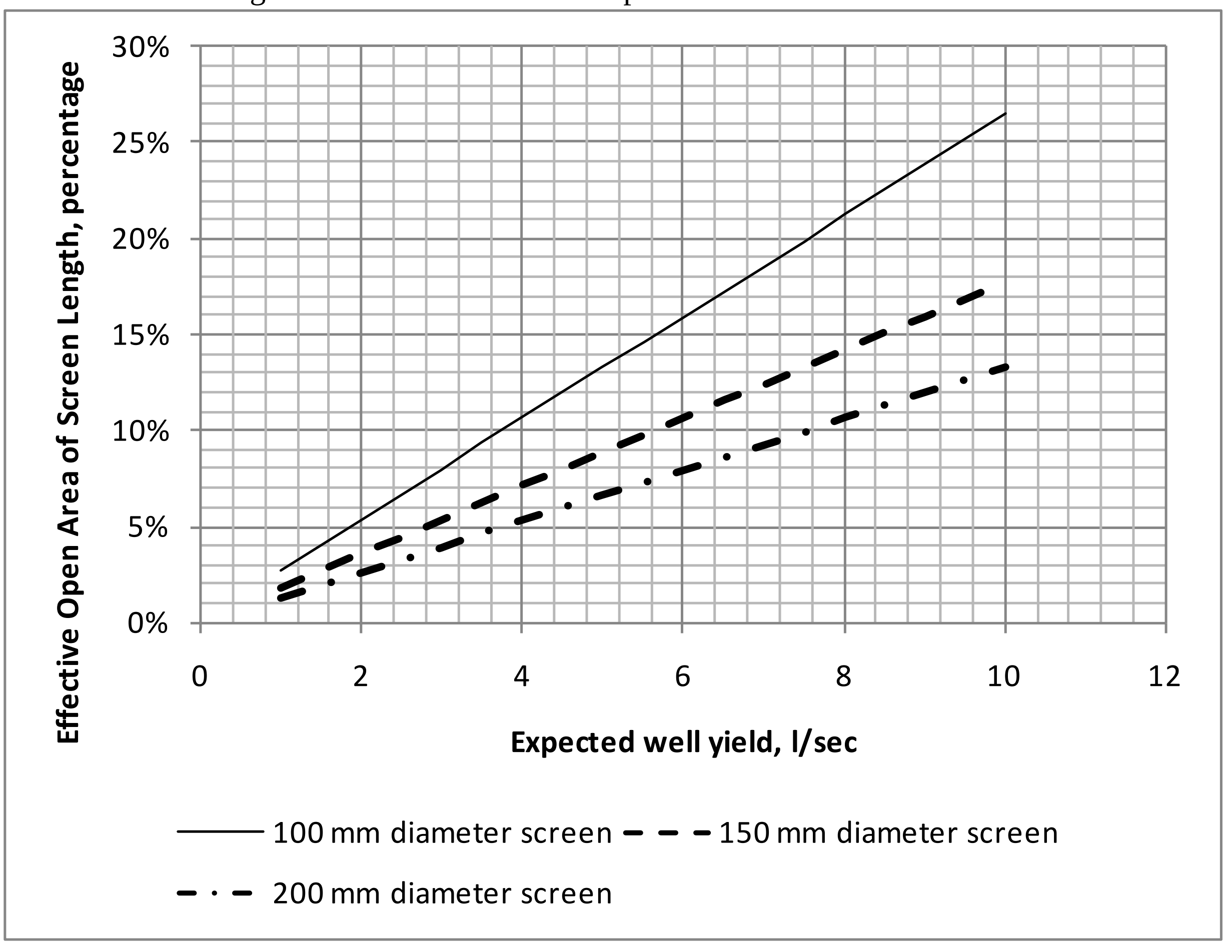
9.5 WELL SCREEN: The well screen and attached fittings shall be constructed entirely of corrosion resistant stainless steel unless specifically authorized by AED. Steel screens shall be made from Type 304 stainless steel meeting the requirements of AWWA A100. High chloride concentrations will quickly corrode other metals. When allowed, PVC pipe screens shall be manufactured from Schedule 80 PVC pipe. Screens made of UPVC pipe material shall not be permitted. The screen slot pattern shall be continuous slot, wire wound or slotted PVC pipe design. Slot openings shall be continuous around the screen, spaced to provide open area required for maximum entrance velocity criteria, but be consistent with the strength requirements, and should be V-shaped toward the inside of the screen to reduce clogging. Slot sizes shall be typical sizes per manufacturer specifications (see Table 2). Metal screens shall be used for wells greater than 80 meters in depth. The minimum inside diameter of the well screen shall be 150mm. Minimum total length of PVC screens installed in the permanent well shall be four (4) meters. Minimum total length of steel screens shall be two (2) meters. Well screens shall provide adequate transmitting capacity to limit the entrance velocity to less than 0.03 m/sec (0.1 ft/s). The selected screen slot design shall be based on standard manufacturer specifications and meet the minimum effective open area required for entrance velocity criteria. Well screen design information shall be submitted to the project COR for approval prior to installation. In a gravel pack well, the screen shall have a slot size based on the gradation of the filter material which is indicated in 9.7 GRAVEL-PACKED WELL. Screens shall be machine milled by a recognized screen manufacturer and not hand cut in the field. Field fabricated screens are not permitted. Appendix B shows examples of unacceptable and acceptable well screens. The well screen shall be directly connected to the top of the inner casing. The bottom of the screen shall be sealed with a positive closure. A wash-down shoe may be used if desired. The screen used in a gravel-packed well shall be carefully lowered into the water-bearing strata and be centered in the hole. In a naturally developed well (see 9.6 NATURALLY DEVELOPED WELL), the slot size of the screen will be based on a mechanical sieve size analysis of the natural water bearing sediments. The well screen and all accessories required for satisfactory installation shall be essentially standard products of reliable manufacturers regularly engaged in the production of such equipment. Field welding of screen components shall be accomplished using products made to weld such products together in a reliable manner. Well Screen and Gravel Pack Submittal information shall include:

(a) Number of screens and depth of setting in the well.
(b) Size of well screen inside and outside diameters and length.
(c) Pipe material (material schedule and specification).
(d) Standard slot opening, mm
(e) Effective open area of screen (sq cm per meter)
(f) Transmitting capacity (liters/meter)
(g) Sieve analysis of the material to be screened
(h) Calculations supporting screen slot size
(i) Photo of screen slot pattern
(j) Results of Gravel Pack selection analysis.

TABLE 2 Typical Effective Open Area for Slotted Well Screens

Nominal Well Screen Diameter	Screen Slot Size		Steel Continuous Slot		PVC Continuous Slot		PVC Slotted Pipe	
mm	No	mm	cm2/m	%	cm2/m	%	cm2/m	%
100	20	0.508	931	25	-	-	-	-
100	60	1.524	1,905	52	1,100	30	381	11
150	30	0.762	1,693	25	1,206	18	550	8
150	60	1.524	2,857	41	1,968	29	995	14
150	95	2.413	3,492	51	-	-	-	-
200	30	0.762	1,629	16	-	-	-	-
200	60	1.524	2,857	28	-	-	-	-
200	95	2.413	3,851	38	-	-	-	-
200	125	3.175	4,529	45	-	-	-	-

Figure 1 Minimum Effective Open Area versus Well Yield



9.6 NATURALLY DEVELOPED WELL:

9.6.1 GENERAL: In water bearing coarse grained material defined as gravel, cobbles, and conglomerate more water can be obtained by natural development of the permeable zone around the well screen than using a gravel pack. After setting the surface casing, a naturally developed well shall be initially drilled by reaming the test hole from the ground surface to the lower level of the water-bearing strata. The well casing and screen shall not be less than 150mm in diameter. The hole shall be of sufficient size to leave a concentric annular space of not less than 50mm between the outside of the casing and the walls of the hole. A grouting basket shall be used to keep the grout from invading the zone around the well screen. The space around the casing shall be filled with cement grout as hereinbefore specified. After grouting is completed, drilling operations shall not be resumed for at least 24 hours to allow proper setting of the grout. After the grout has set, the well shall be developed by pumping or bailing until the fine grained material is removed.

9.7 GRAVEL-PACKED WELL:

9.7.1 GENERAL: Gravel-packed wells shall be constructed in fine grained aquifer materials consisting of silty sand, sand and fine gravel (less than material 3 mm in size). The space around the well screen shall be filled with gravel pack material as described hereafter; either gradation A or gradation B shall be used based on a mechanical sieve size analysis of the natural water bearing sediments. The term “gravel-packed well” does not actually mean that the filter material is always gravel sized material. The filter material may be sand sized. The gradation depends upon the size of the aquifer material that yields the water. Coarse grain aquifers shall be considered to be any water bearing stratum that has more than 50 percent of the individual particle sizes greater than 6 mm in diameter. Aquifers with greater proportion of fine sand and silt (less than 6 mm size) shall be considered fine grained aquifers. After setting the surface casing, a gravel-packed well shall be initially drilled by reaming the test hole from the ground surface to the lower-most level of the water bearing strata. The casing and screen shall be as herein specified and shall be not less than 150mm in diameter. The hole shall be of sufficient size to leave a concentric annular space of not less than 50mm between the outside of the screen and casing and the walls of the hole. The gravel pack shall be 1.5 times the length of the screen section it surrounds. For example if the screen is 3 meters in length the gravel pack shall be 4.5 meters in length straddling the screen on the top and bottom. The space around the screen shall be filled with filter material as hereinafter specified. The well casing shall be grouted in with cement grout as hereinafter specified. After grouting is completed, drilling operations shall not be resumed for at least 24 hours to allow proper setting of the grout. The hole below the outer casing shall penetrate the water bearing strata a sufficient depth to install the well screen and produce the required yield without causing excessive velocities through the well screen. The casing shall be connected directly to the top of the well screen and extend up to one foot above the ground surface.

9.7.2 GRAVEL-PACK: After the screen and casing have been installed, filter material shall be installed around the screen by filling the entire space between the screen and the walls of the hole with filter material. The filter shall have a wall thickness of 50mm, measured from the outer edge of the screen to the wall of the hole. Filter material shall be of properly sized, graded, well-rounded natural sand and gravel suitable for the strata encountered. Angular aggregate shall not be used. The filter material shall be of such size as will allow the maximum flow of water into the well and prevent the infiltration of sand. It shall be washed siliceous material, reasonably smooth and round and free of flat or elongated pieces as well as dirt, vegetable matter or other foreign matter. The Driller shall demonstrate to the COR that the filter material is suitable for the conditions prior to placement and submit a gradation of the material for approval. In no case will improperly sized filter material be added around the screen.

Gravel pack gradations shall be based on the aquifer particle size. Silty sand particle size aquifers shall use Gradation A (Table 3), and gravel and larger particle size material shall use Gradation B (Table 4).

TABLE 3 Gradation A Gravel Pack Materials

Material for gravel pack in silty sand aquifers - Shall consist of stone containing rounded shapes and surfaces with no flat surfaces having the following gradation:

Sieve Size	% Total Wt. Passing
12.5 mm	100
4.75 mm	75 +/- 13
1.18 mm	25 +/- 15
0.425mm	8 +/- 4

TABLE 4 Gradation B Gravel Pack Materials

Material for gravel pack in sandy gravel including cobbles - Shall consist of stone containing rounded shapes and surfaces with no flat surfaces have the following gradation:

Sieve Size	% Total Wt. Passing
40 mm	100
32 mm	75 +/- 13
16 mm	25 +/- 15
9 mm	8 +/- 4

All aggregate shall contain less than 5% by weight rock powder, silt, clay, shale, clay lumps, coal, lignite, soft stone, or other deleterious materials.

9.7.3 PIPE OR CONDUCTOR FOR FILTER PLACEMENT: If possible, a pipe or conductor having an inside nominal diameter of not less than 25mm shall be lowered to the bottom of the well between the drilled hole and the screen. It shall be so arranged and connected at the surface of the ground to water pumping and filter placement equipment so that water and filter material, fed at uniform rates, are discharged through it as the filter fills the hole from the bottom up. The filter sand and water conductor shall be raised at the rate that will keep the bottom of the pipe approximately at the filter material level in the hole.

9.8 ROCK WELL: A rock well shall be initially drilled from the ground surface to a point at least 3 meters below the top of consolidated material (bedrock), but not less than 10 meters below the top of the rock and the bottom of the casing shall be set at this bottom elevation. The finished internal diameter of the casing shall be not less than 150mm, and the hole shall be drilled to a sufficient diameter so as to leave a concentric annular space not less than 37mm (1 1/2-inches) between the casing and the walls of the hole. A temporary casing may be used to prevent caving of the hole walls, but the temporary casing must be removed when the grouting of the permanent casing is performed. This space shall be filled with cement grout in a manner as previously specified. After the grouting is completed, drilling operations shall not be resumed for at least 24 hours to allow proper setting of the grout. Drilling into the water-bearing rock strata shall be resumed after the grout has set. A hole at least 150mm in diameter, concentric with the casing above, shall be drilled into the water-bearing rock a sufficient depth to produce the required amount of water without causing excessive velocities of the water through the rock.

10. WELL DEVELOPMENT: After completion, the well shall be thoroughly developed. The developing equipment shall be of sufficient capacity to remove all drilling fluids, sand, rock cuttings or any other foreign matter. The wells shall be thoroughly cleaned from top to bottom before beginning the well tests. The recommended type of development for stainless steel screened wells is hydro-jetting; however surge blocks, air-development or other development techniques are permissible at the option of the Contractor. The well shall be disinfected before removing the test pump and collecting samples for determining the water quality (see 13. DISINFECTION).

11. WELL PUMPS:

11.1 PERMANENT WELL PUMP: The pump and motor diameter shall be at least 25 mm smaller than the inside diameter of the well screen or casing, whichever is smaller, in order to allow it to be removed for servicing after the buildup of scale on the outside of the pump and inside of the screen and casing. Before any installation of the permanent pump in the well, a pump design approval shall be submitted to the COR for approval. Pump Design Approval submittals shall include the following information:

(a) Capacity of well from test well submittal.
(b) Size of permanent well diameter and depth.
(c) Depth of static water level below top of well.
(d) Power source and pump motor electrical power requirements.
(e) Expected well draw down.
(f) Pump discharge piping diameter, length, fittings and appurtenances (valves, meters, etc.)
(g) System total dynamic head required by well pump.

(h) Pump design discharge rate.
(i) Selected pump curve and duty point from manufacturer.
(j) Pump/motor product material specifications from manufacturer.

11.2 HAND PUMP: A standard hand pump with seal and air gap shall be installed on the permanent well discharge piping to discharge at concrete pad around well if required by the contract technical requirements. The hand pump shall be capable of pumping at a minimum pressure head of 138 Kpa (20 psi) in the event there is either a loss of power supply or a pump failure in the water well system.

11.3 WELL HEAD COMPLETION: A stainless steel check valve (if not on the pump discharge piping), isolation valve, sampling port, and well discharge tantalizer shall be installed on the pump discharge pipe line, as minimum appurtenances, between the well head and the water storage treatment tanks. A water level measurement port shall be provided at the well head. Additional appurtenances such as flow meter, air release valve, and chlorination treatment piping may be required depending upon the contract technical requirements. Any structure built over the well must have a large door in the roof that allows for easy removal of the pump piping and pump using an overhead crane. Examples of well head construction are shown in Appendix B.

12. TESTS:

12.1 TEST FOR QUALITY OF WATER: During the testing of the test well and again during the yield and drawdown test in the permanent well, the Contractor shall schedule to obtain a preliminary sample of the water in suitable containers and of sufficient quantity to have bacterial, physical and chemical analyses made in accordance with the following Table 5 to determine if the water is potable. The word "potable" for purpose of this contract is further defined as water that is suitable for drinking by the public, i.e., good, clear water free from objectionable amounts of harmful bacteria and chemical and physical properties, as defined by References 1.1 or 1.2. Sampling shall be performed by qualified personnel who must obtain sampling kits and schedule their site visit to obtain the samples as directed. The coordination with the COR for the sampling and analysis should begin at the beginning of the contractual period. Complete requirements for water quality are found in Appendix A of TM 5-813-3 (UFC 3 230 08a Water Supply Water Treatment, January 2004).

TABLE 5

WATER QUALITY ANALYSIS TABLE

Physical Characteristics

Color	Temperature
Threshold odor number	pH value
Turbidity	

Chemical Characteristics (Expressed as mg/L)

Arsenic	Total Hardness as $Ca(CO)_3$
Barium	Cadmium
Chromium	Copper
Lead	Mercury
Selenium	Silver
Zinc	Sulphates as SO_4
Fluoride as F	Chlorides as Cl
Manganese as Mn (dissolved and total)	Conductivity
Iron as Fe (dissolved and total)	Nitrites as NO_2
Total Dissolved Solids	Nitrates as NO_3
total coliform/fecal coliform (bacteria)	

12.2 TEST FOR SAND: After the final well is fully developed and while the development pump is still installed, a test to confirm the actual degree of sand which will infiltrate the well shall be conducted. The well shall be allowed to rest for at least one hour, then pumping shall begin at the full design well yield. Driller shall pump or bail the well until the water pumped from the well shall be substantially free from clay, silt, and sand (< 8.0 mg/l) as measured by an Imhoff cone container or until the water is clear (which shall be determined by the COR. The Imhoff cone container results shall be based on the average results of five samples taken from a large barrel or other tank during the pump test. The samples shall be taken 15 minutes after the start of the pump test, after 25%, 50% and 75% of the pump test duration, and near the end of the pump test. After completion of the well, unless the permanent pump is immediately installed, the Contractor shall cap the well to prevent contamination of the well.

12.3 TEST FOR YIELD AND DRAWDOWN AND RECOVERY: Upon completion of the permanent production well, the Driller shall install the pump with discharge piping of sufficient size and length to conduct the water being pumped to a point of safe discharge and all equipment necessary for measuring the rate of flow and the water level in the well. A continuous 6-hour pumping test shall be conducted with the pumping rate and drawdown recorded at appropriate intervals indicated in Table 6 between 0 min and 360 min.

TABLE 6 Time Intervals for Drawdown
and Recovery Readings

0 minutes	120 minutes	660 minutes
2 minutes	150 minutes	720 minutes
4 minutes	180 minutes	780 minutes
6 minutes	210 minutes	840 minutes
8 minutes	240 minutes	900 minutes
10 minutes	270 minutes	960 minutes
15 minutes	300 minutes	1020 minutes
20 minutes	330 minutes	1080 minutes
25 minutes	360 minutes	1140 minutes
30 minutes	390 minutes	1200 minutes
40 minutes	420 minutes	1260 minutes
50 minutes	450 minutes	1320 minutes
60 minutes	480 minutes	1380 minutes
80 minutes	540 minutes	1440 minutes
100 minutes	600 minutes	

Repeat the reading schedule above for duration of recovery portion of the test after the pump is shut off.

13. DISINFECTION: Immediately after the well is completed, unless the permanent pump is ready for installation, the well shall be sterilized by adding chlorine or hypochlorite in such volume and strength and shall be so applied that a concentration of at least 50 ppm shall be obtained in all parts of the well. The chlorine or hypochlorite shall be prepared and introduced into the well in a manner approved by the COR and shall remain in the well for a period of at least twelve hours. Section A1-10 of AWWA Specification A100 describes acceptable methods of sterilization of a well. After the contact period, the well shall be pumped until the residual chlorine content of the well water removed is 1 ppm or less.

14. ABANDONMENT OF WELLS: In the event that the Contractor fails to construct a well of the required capacity, or should he abandon the well because of loss of tools or for any other cause, the Contractor shall fill the entire hole with grout and remove the casing to the satisfaction of the site COR.

15. CLEAN-UP: Upon completion of the well and other incidentals, all debris and surplus materials resulting from the work shall be removed from the job site. The drilling fluid shall be pumped out and properly disposed of and the excavation for the sump backfilled suitable to the site COR.

16. QUALITY CONTROL: The Driller shall establish and maintain quality control for operations under this section to assure compliance with specification requirements and maintain records of his quality control for all materials, equipment, and construction operations, including but not limited to the following:

(a) Protection of existing facilities.
(b) Protection of quality of water.
(c) Drilling, logging, and testing of test holes.
(d) Drilling operations for well.
(e) Setting of casings, screens, and grouting of casings.
(f) Placement of filter material, if used.
(g) Well development.
(h) All testing of finished well.
(i) Well disinfection.
(j) Filling abandoned test hole or well if required.

A copy of these records and tests, as well as records of corrective action taken, shall be maintained by the Driller for review if requested by the COR.

17. SUBMITTALS: Appendix B contains a flow chart of the well construction process and identifies the points where submittals are expected. The following summarizes the submittals previously listed in greater detail in this specification.

(a) Driller Log Submittal.
(b) Test Well Approval Submittal.
(c) Well Screen and Gravel Pack Submittal.
(d) Pump Design Approval Submittal

18. PAYMENT: Payment for the production water well, except test hole (and test well), will be included in the contract lump sum price for "Water Well" which payment shall constitute full compensation for all costs in connection therewith. Payment for test hole and test well, if permanent well cannot be developed, as determined by the Contracting Officer, will be made at the contract unit price per linear foot for "Test Hole (and Test Well)", which payment shall include all labor, mobilization and demobilization of equipment, drilling, testing, materials, and other incidentals necessary for the test hole and (test well). Payment for test hole and (test well) used in the permanent well will be included in the contract lump sum price for "Water Well." Payment for linear footage of hole drilled not resulting in a permanent well will be paid for as linear footage of "Test Hole (and Test Well)."

Appendix B - Water Well Construction Process

	Preliminary Well Development		Production Well Development		Well Pump and Wellhead Completion
1	Pre Construction Meeting	10	Well Installation	19	**Submittal** Pump Design Approval
2	Site Preparation	11	Install Screen and Final Casing	20	Final Well Pump and Discharge Piping Installation
3	Surface Casing Installation	12	Install Gravel Pack, Bentonite Seal and Surface Grout Seal	21	Install pump Water Level Sensor, Piping, etc
4	Pilot Test Hole Drilling	13	Well Development	22	Disinfect Well
5	Geologic Logging	14	Swab and Airlift	23	Well Head Completion Including Building
6	Groundwater Sampling	15	Pump Performance and Sand Tests	24	***Submit*** Well Completion Report
7	Conslutant Determines Well Design	16	Well Completion and Testing	25	***Submit*** Contents of previous Submittals
8	** Submittal** Test Well Approval	17	Aquifer Test Using Test Pump	26	***Submit*** Pump Equipment and Other material and Product Warranties
9	Contractor Reams Pilot Borehole to Final Diameter	18	Analyze Pump Test Data and Calculate Pump duty Point (TDH, Q)		

Appendix C

Examples of Unacceptable and Acceptable Well Construction (Source: Statement of work Military Water Well Construction, Testing and Completion, United States Forces, Afghanistan, 2009)

Figure 4. Example of unacceptable, locally fabricated well screen. Slots were cut into the steel casing using a cutoff wheel or grinder (yellow ovals), creating 0.05% openings per foot. Folded knife is 4-in long.

Figure 5. Example of approved stainless steel slotted screen with threaded connections (folded knife is 4-in long). Minimum opening area is 15% of the screen surface per foot.

Figure 6. PVC Schedule 40 slotted well screens

Figure 6. Unacceptable wellhead completion examples. Upper panel - casing sticks up <1-inch above the floor, has an inadequate sanitary seal, and has inadequate well pad slope and floor drainage. Lower panel – no sanitary seal or well house over well, and the well pad has no slope Both examples are missing totalizers, water sampling ports, water level measuring ports.

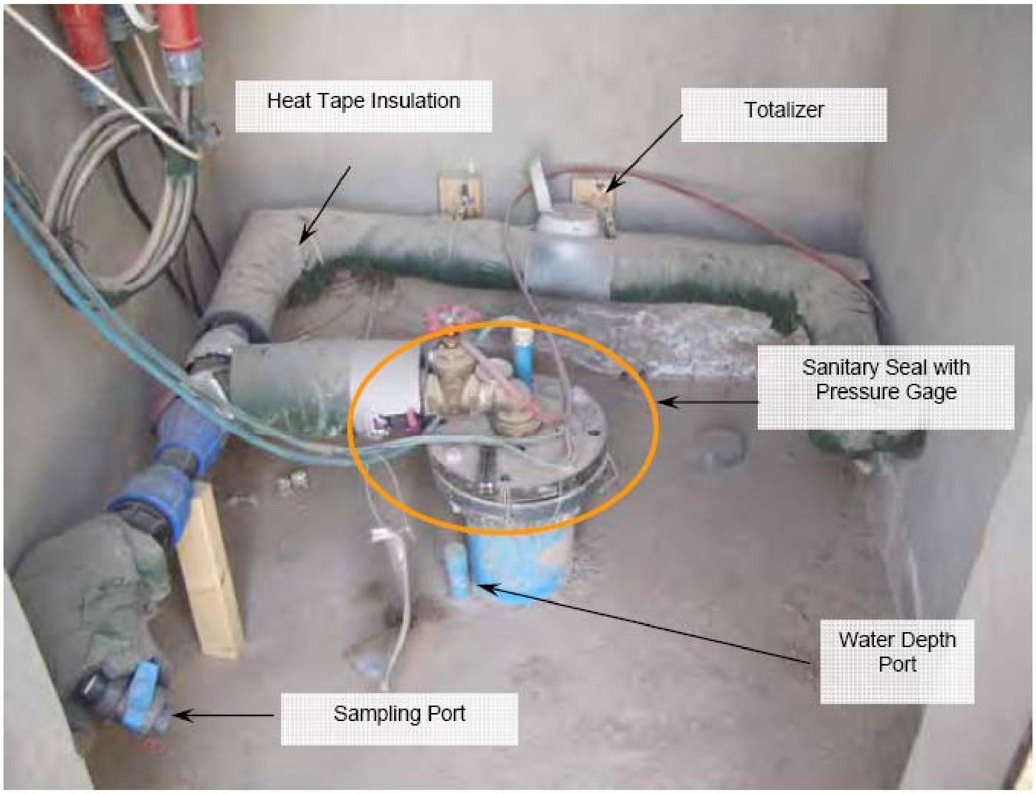


Figure 7. Acceptable wellhead completion, with totalizer (rear center), raw water sample port (lower left), sanitary port for measuring water level (left of 8-in blue well casing), and adequate sanitary seal on well casing (center).

Appendix D

Well Pump Hydraulic Sizing Example

1. General

The purpose of this appendix is to provide design and submittal requirements to contractors for any project requiring well pump design and installation. Water well pump design and selection are covered in Reference 12.

2. Well Data

Submersible well pumps are the most common water well pumps installed at USACE-AED project sites. For submersible pumps the drawdown depth below grade (BG) must be first determined from pumping tests at the rate or (if step drawdown test) within the range of the pumping rates used in the test.

3. Pump Curve Selection

a) System Head Curve. The first step in the pump selection process is to determine the region of operating head curve for the pump piping system. The head curve is determined from the total dynamic head (TDH) required in the piping system at the design flow rate. The TDH is the total discharge head (h_d) minus the total suction head (h_s). For submersible pumps, h_s is a positive value, in other words the level of the dynamic water level above the pump intake is subtracted instead of added from the total discharge head to obtain TDH:

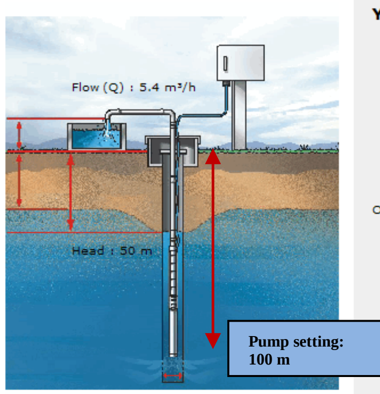
$$TDH = h_d - (h_s)$$

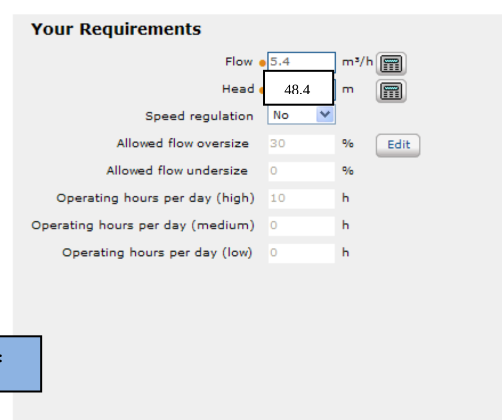
The total discharge head (h_d) is the sum of the static discharge head (h_{sd}), the discharge velocity head (h_{vd}) at the pump discharge flange and the friction head (h_{fd}) in the discharge line.

$$h_d = h_{sd} + h_{vd} + h_{fd}$$

A sketch of the well installation is required to be submitted in the design analysis showing information similar to the figure to the right.

In this example, the pump setting (h_{sd}) is 100 m (BG), the dynamic drawdown is 50 m, and therefore h_s is equal to -50m. The well pump discharge pipe diameter is 50 mm (2 in) and the design flow is 1.5 l/s (5.4 m^3/h) based on 10 hours per day average operation time. Velocity head, h_{vd} is estimated at 0.002 m, and friction loss, h_{fd}, for 125 m of discharge piping (to the tank inlet) is approximately 1.5 m. Therefore h_d=100-0.002-1.6=98.398 m, TDH = 98.398-50=48.398, say 48.4 m.





Velocity head is calculated as shown by the following equation.

$$h_v=v^2/2*g_c$$

Where:

v=Q/A=flow velocity at the discharge of the pump (m/sec)
g_c=gravitational constant=9.81 m/sec^2
Q=flow (m^3/sec)
A= pipe area (m^2) =π*(D^2/4)
D= pipe diameter (m)

Discharge friction head (h_{fd}) is the head required to overcome resistance to flow in the pipe and fittings. It is dependent upon the size, condition and type of pipe, number and type of pipe fittings, flow rate and nature of the liquid is calculated by the following equation.

$$h_f=L[(v/(kC))*(4/D)^{0.63}]^{1/0.54}$$

Where:

L=equivalent length of pipe and fittings (m)
v=flow velocity in pipe (m/sec)
k=0.85.
C=Hazen-Williams coefficient, assumed 150 for PVC and new SCH 40 steel pipe
D=pipe diameter (m)

The discharge friction head (h_{fd}) will need to be calculated for specific flow rates from the pump.

b) Pump Power

Pump brake power is calculated using the following equation:

$$P=(HQ)/(102*e)$$

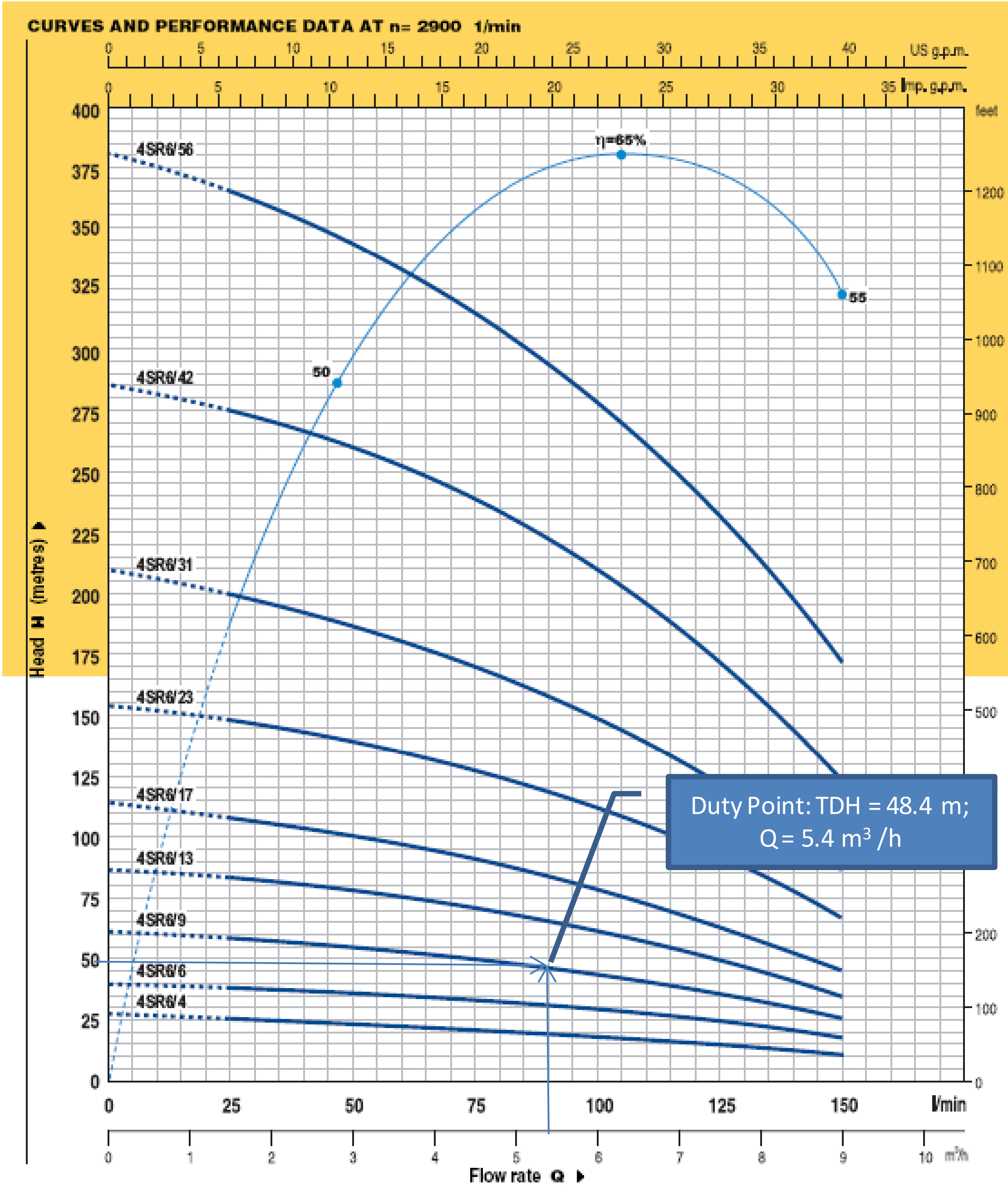
Where:

P=break power required, kW
H=total dynamic head, m
Q=volume of water discharged, L/s
e=Combined efficiency of pump and motor, from manufacturer's data

For this example given here the brake power required is 1.1 kW, based on 1.5 L/s discharge rate, 48.4 meter TDH, and efficiency of 0.64.

The pump curve is shown in the next figure along with the duty point calculated for the well pump installation. Because the well pump rate and drawdown obtained during the pump test are interrelated, it is important that the well pump be selected based on actual data obtained from tests and not assumed from hypothetical calculations of drawdown. Furthermore, the pump motor power must be limited that required to produce the pump test flow rate. Larger pumps than required may result in the pump drawing down the well significantly farther than occurred during the test; increased entrance velocities through the screen can occur resulting in clogging the screen and ultimately destroying the well capacity, and leading to pump motor failure.

Typical pump curve and duty point designation



TYPE		POWER		Q m³/h	0	1.5	3.0	4.5	6.0	7.5	9.0
Single-phase	Three-phase	kW	HP	l/min	0	25	50	75	100	125	150
4SR6m/4	4SR6/4	0.55	0.75	H metres	27	26	24	22	19	15	11
4SR6m/6	4SR6/6	0.75	1		40	38	36	33	29	24	17
4SR6m/9	4SR6/9	1.1	1.5		61	58	54	50	44	35	26
4SR6m/13	4SR6/13	1.5	2		87	83	79	71	61	49	35
4SR6m/17	4SR6/17	2.2	3		114	107	100	91	79	62	45
—	4SR6/23	3	4		154	149	138	128	112	92	67
—	4SR6/31	4	5.5		210	200	186	170	149	121	86
—	4SR6/42	5.5	7.5		295	276	258	240	212	170	124
—	4SR6/56	7.5	10		390	365	340	315	280	233	173

Q = Flow rate H = Total manometric head

Tolerance of the performance curves according to EN ISO 9906 App. A.